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University of Chicago

Graduate School of Business
1101 East 58th Street, Chicago, Illinois 60637

January 31, 1996

Dr. Richard O. MacPeters
Lab for Atmospheres
NASA/ Goddard Space Flight Center
Greenbelt, MD 20771

Dear Dr. MacPeters:

Please find enclosed the annual progress report for the project NAG6-2846 and NAG5-2849 "Statistical Analysis of Atmospheric Temperature and Ozone Data for Trend Features and Comparisons with Model Calculations", under the direction of George C. Tiao of the University of Chicago Graduate School of Business and Gregory C. Reinsel of the University of Wisconsin Department of Statistics. I have also included a revised budget for the second year of the University of Chicago portion of the project. We have used February 15, 1996 as the starting date of the next 12 month phase of the grant with the understanding that NASA will issue a no-cost extension for the period between this date and the original termination date of our first year, per the instructions of Gloria Blanchard.

Sincerely,

G. Tiao

George C. Tiao
W. Allen Wallis Professor of Statistics

Institutional Endorsement
Mary Ellen Sheridan

Mary Ellen Sheridan, Ph.D.
Assistant Vice President for Research
3/1/96

A Research Progress Summary to National Aeronautics and Space Administration on

"Statistical Analysis of Atmospheric Temperature and Ozone Data for Trend Features and Comparisons With Model Calculations"

G. C. Reinsel, University of Wisconsin, Madison, and G. C. Tiao, University of Chicago

The following is a summary of research progress during the first year period ending January 14, 1996 on the above-titled project for the NASA grants NAG5-2846 and NAG5-2849 to the University of Wisconsin and the University of Chicago, respectively. Our research efforts and results to date have been concentrated primarily in the following areas:

(a) Seasonal Trend Analysis of Ground-based and TOMS Satellite Total Ozone Data

A seasonal trend analysis of published Dobson (including stations' newly revised and Brewer-simulated Dobson) total ozone data through 1991 from a network of 56 stations has been performed, using three different data periods. The seasonal trend model considered allows for a different trend for each month of the year to examine the seasonal nature of ozone trend behavior, and also includes an F10.7 cm solar flux term and a 50 mb equatorial wind QBO term. Random effects models for the individual station seasonal trend estimates, to allow for individual station and regional trend variations, are used to combine individual station trend estimates to obtain overall trend estimates in ozone for different seasons of the year as a function of latitude. The trend results for the longest data period 1964–1991 indicate substantial negative trends in ozone in the higher northern latitudes during the winter and spring seasons, of the order of −2.5% per decade, some evidence of negative trend in the higher southern latitudes (30°S–55°S) during all seasons, and trends close to zero for all seasons over the 30°S–30°N latitude range. For the shortest data period, November 1978 through 1991, there is an indication that trends have become more negative in the higher northern latitudes, especially during the winter and spring seasons, and also in the higher southern latitudes in all seasons. A seasonal trend analysis of zonal averages of total ozone mapping spectrometer (TOMS) satellite total ozone data for the comparable period November 1978 through 1991 has also been performed, and moderately good agreement is found between trends in Dobson and TOMS data over this period. These results are described in detail in Reinsel et al. (1994b).

(b) Comparison of Trend Analyses for Umkehr Data Using New and Previous Inversion Algorithms

Ozone vertical profile Umkehr data for layers 3–9 (approximately 15 to 49 km in altitude) obtained from 12 stations, using both previous and new inversion algorithms, have been analyzed for trends. The trends estimated for the Umkehr data from the two algorithms were compared using two data periods, 1968–1991 and 1977–1991. Both nonseasonal and seasonal trend models were fitted, using statistical trend models that also included F10.7 cm solar flux and stratospheric optical thickness terms to account for solar cycle variations in ozone and errors in the Umkehr measurements caused by stratospheric aerosols from volcanic activity. The overall annual trends in Umkehr data are found to be significantly negative, of the order of –5% per decade, for layers 7 and 8 using both inversion algorithms. The largest negative trends occur in these layers under the new algorithm, whereas in the previous algorithm the most negative trend occurs in layer 9. The trend estimates, both annual and seasonal, are substantially different between the two algorithms mainly for layers 3, 4, and 9, where trends from the new algorithm data are about 2% per decade less negative, with less appreciable differences in layers 7 and 8. The trend results from the two data periods are similar, except for layer 3 where trends become more negative, by about –2% per decade, for 1977–1991. More details concerning the trend results from this analysis are given in Reinsel et al. (1994a).

(c) Comparison of Stratospheric Ozone Trends By Examination of Umkehr and Ozonesonde Data

The nonseasonal and seasonal trend behavior of ozone profile data has been examined using both ozonesonde and Umkehr measurements in a consistent manner, covering the same time period of 1968–1991. This provides a useful overall comparison of trend results between the two data sources. In this trend analysis study, ozone profile data from 10 ozonesonde stations and 11 Umkehr stations, all located in the mid-latitudes of the northern hemisphere (about 30°N to 55°N), were considered. Our trend results obtained reaffirm the finding of significant negative ozone trends in both the lower stratosphere (15–20 km), of about –6% per decade, and upper stratosphere (35–50 km), of about –6% per decade, separated by a nodal point of little or no trend in the region of 25–30 km altitude. The upper stratosphere decrease is, apparently, associated with the classic gas phase chemical effect of the chlorofluorocarbons, whereas the cause of the lower stratospheric decline is still under investigation, but may well be associated with the chlorine and bromine chemistry in this altitude region. A detailed description of the analysis and trend results is presented in Miller et al. (1995).

(d) Comparison of Stratospheric Ozone Trends and Solar Effects Using Umkehr and Combined SBUV, SBUV/2 Satellite Data

The stratospheric ozone trends and responses to the 11-year solar cycle (represented by the F10.7 cm radio flux) are estimated from both ground-based Umkehr records and the combined Nimbus 7 SBUV and NOAA 11 SBUV/2 satellite records, and the results from the two data sets are compared. The analysis considers ozone data for the northern mid-latitudes (30°N–50°N) at altitudes between 25 and 45 km for the period 1977 through June 1991. In particular, the effects of spatial sampling differences between the two data sets on the estimated trend and solar signals is investigated. The trends estimated from the two ozone data sets are nearly identical at all altitude levels except 35 km, where the Umkehr data indicate a somewhat more negative trend. The trend is approximately zero near 25 km, but becomes more negative in the upper stratosphere, reaching nearly –7% per decade in the 40–45 km region. The upper stratospheric decreases are consistent with chemical model results and are associated with the gas phase chemical effect of CFC and other ozone-destroying chemicals. The ozone correlations with the F10.7 cm solar flux are similar in the two ozone data sets, with statistically significant in-phase solar-induced ozone variations above 30 km. Estimates of the solar cycle effect on the ozone time series at 40–45 km altitude obtained from a regression-time series model indicate solar-induced variations in ozone of about 4.5% from solar cycle minimum to maximum. Analysis of the satellite overpass data at the Umkehr station locations shows that the average trend of the ground-based data from the 11 Umkehr stations is a good approximation for the trend in the 30°N–50°N zonal mean satellite series. The results of this analysis are presented in detail in Miller et al. (1996).

(e) Trend Analysis of Lower Stratospheric Rawinsonde and MSU-4 Temperature Data

A preliminary trend analysis of the lower stratospheric temperature data from the Microwave Sounding Unit (MSU) channel 4 satellite source for the period 1979–1992 has been initiated, and comparison of these temperature data and their trend behavior with corresponding data and trends constructed from available rawinsonde station temperature data for the same time period is considered. Rawinsonde temperature data recorded at 10 pressure levels from about 225 stations were used and a vertically-weighted average temperature series was constructed from each station's data, using weights over the different pressure levels that are consistent with the MSU channel 4 temperature data weighting function. Some basic comparisons of the rawinsonde-based temperature data with colocated MSU channel 4 data have been performed, and substantial differences in trend behaviors have been noticed in certain cases. The differences in behavior between rawinsonde-based and MSU-4 temperature data seem to be similar among many of the rawinsonde stations within a given geographical/political region, but the patterns of disagreement between rawinsonde and MSU-4 data are not consistent among the different regions. Further study and analysis of these data are needed.

Journal Publications

Miller, A. J., S. M. Hollandsworth, L. E. Flynn, G. C. Tiao, G. C. Reinsel, L. Bishop, R. D. McPeters, W. G. Planet, J. J. DeLuisi, C. L. Mateer, D. Wuebbles, J. Kerr, and R. M. Nagatani (1996). Comparisons of observed ozone trends and solar effects in the stratosphere through examination of ground-based Umkehr and combined SBUV, SBUV/2 satellite data. To appear in *J. Geophys. Res.*, 101.

Miller, A. J., G. C. Tiao, G. C. Reinsel, D. Wuebbles, L. Bishop, J. Kerr, and R. M. Nagatani, J. J. DeLuisi, and C. L. Mateer (1995). Comparisons of observed ozone trends in the stratosphere through examination of Umkehr and balloon ozonesonde data. *J. Geophys. Res.*, 100, 11,209–11,217.

Reinsel, G. C., W. K. Tam, and L. H. Ying (1994a). Comparison of trend analyses for Umkehr data using new and previous inversion algorithms. *Geophys. Res. Lett.*, 21, 1007–1010.

Reinsel, G. C., G. C. Tiao, D. J. Wuebbles, J. B. Kerr, A. J. Miller, R. M. Nagatani, L. Bishop, and L. H. Ying (1994b). Seasonal trend analysis of published ground-based and TOMS total ozone data through 1991. *J. Geophys. Res.*, 99, 5449–5464.